

7B, a tendency of the photocurrent per unit energy according to a wavelength was similar to a tendency of the absorbance spectrum. As a result, a photocurrent was generated by surface plasmon absorbance of a photoelectric device illustrated in FIG. 6.

[0085] FIG. 8 illustrates a nanostructure including nanopatterns formed in a direction.

[0086] Referring to FIG. 8, the nanostructure may include a lower structure 10, a two-dimensional material layer 12 formed on the lower structure 10, and nanopatterns 44 that are formed on the two-dimensional material layer 12 substantially in one direction D1. The nanopatterns 44 may have a rod shape having a longer length with respect to a width of a cross-section, and the cross-section of the nanopatterns 44 may be, without limitation, a circle, an oval, or a polygon.

[0087] The nanopatterns 44 formed substantially in one direction D1 may indicate that at least 50% of the nanopatterns 44 are uniformly aligned lengthwise in the direction D1. Lengths of the nanopatterns 44, which are rod-shaped, and diameters or surface areas of the cross-sections of the nanopatterns 44 do not necessarily have to be identical. For example, the nanopatterns 44 may include rod-shaped nanopatterns having cross-sections of substantially the same size but both a relatively long length and a relatively short length. Also, although the nanopatterns 44 have substantially the same length, the nanopatterns 44 may have cross-sections of different shapes or different cross-section diameters or different surface areas. When the nanopatterns 44 are aligned substantially in the same direction D1 and include nanopatterns having different lengths or having cross-sections of different surface areas or different diameters, the nanopatterns 44 may be applied to a multi-band plasmonic photo-detector. Although only the nanopatterns 44 which are rod-shaped are illustrated in FIG. 8, the shape of the nanopatterns is not limited thereto, and nanopatterns of a different shape, for example, spherical nanopatterns may also be partially included.

[0088] When the nanopatterns 44 are formed substantially in one direction D1 as described above, light absorbance may vary according to a polarization direction of incident light. For example, the more similar a polarization direction of light incident to the nanopatterns 44 is to the direction D1 which is the alignment direction of the nanopatterns 44, the more effectively a plasmonic band may be formed, thereby increasing light absorbance. On the other hand, the closer the polarization direction of light incident to the nanopatterns 44 is to a perpendicular direction to the direction D1 which is the alignment direction of the nanopatterns 44, light absorbance may be reduced.

[0089] FIG. 9 illustrates a nanostructure in which distances between nanopatterns are adjustable.

[0090] Referring to FIG. 9, the nanostructure may include a lower structure 10, a two-dimensional material layer 12 formed on the lower structure 10, and nanopatterns 54a and 54b formed on the two-dimensional material layer 12, wherein distances between the nanopatterns 54a and 54b are adjustable. The distances between the nanopatterns 54a and 54b may be adjusted by deforming the lower structure 10. When the lower structure 10 is formed of a flexible material such as polymer, the lower structure 10 may be mechanically deformed to change a length d1 and/or d2 of the lower structure 10. Also, a material such as an organic solvent may be absorbed into or discharged from the lower structure 10 to swell or shrink the lower structure 10 and to thereby

change the length d1 and/or d2. For example, the lower structure 10 may be formed of polydimethylsiloxane (PDMS), and then the two-dimensional material layer 12 and the nanopatterns 54a and 54b may be formed on the lower structure 10. Then, when an organic solvent such as acetone is absorbed into the lower structure 10, the lower structure 10 may be deformed three-dimensionally. As the organic solvent is absorbed into the lower structure 10 so that the lower structure 10 is swelled, distances between the nanopatterns 54a and 54b may be increased. On the contrary, when the organic solvent is discharged from the lower structure 10, the lower structure 10 may be shrunk and the distances between the nanopatterns 54a and 54b may be reduced.

[0091] Although the nanopatterns 54a and 54b including spherical nanopatterns 54a and rod-shaped nanopatterns 54b are illustrated in FIG. 9, this is exemplary, and only spherical nanopatterns 54b may be formed on the two-dimensional material layer 12. The spherical nanopatterns 54b may include nanopatterns having different sizes. Also, the distances between the nanopatterns 54a and 54b may be formed to have a predetermined initial distance between one another, and the distances between all of the nanopatterns 54a and 54b may be uniformly increased or reduced or distances between only some of the nanopatterns 54a and 54b may be increased or reduced according to deformation of the lower structure 10. By adjusting the distances between the nanopatterns 54a and 54b, a range of localized surface plasmon resonance (LSPR) frequency may be changed.

[0092] FIG. 10 illustrates a nanostructure including nanopatterns having a core-shell structure.

[0093] Referring to FIG. 10, the nanostructure may include a lower structure 10, a two-dimensional material layer 12 formed on the lower structure 10, and nanopatterns 64 and 65 formed on the two-dimensional material layer 12. The nanopatterns 64 and 65 may have various forms. For example, the nanopatterns 64 and 65 may include a spherical nanopattern 64 having a core-shell structure and rod-shaped nanopatterns 65 having a core-shell structure. A core region 64a and a shell region 64b of the spherical nanopatterns 64 may be formed of different materials; for example, the core region 64a may be formed of Ag, and the shell region 64b may be formed of Au. However, this is exemplary, and in the other way around, the core region 64a may be formed of Au, and the shell region 64b may be formed of Ag. The spherical nanopatterns 64 having a core-shell structure in which an outer portion of the core region 64a is completely surrounded by the shell region 64b are illustrated, but the exemplary embodiments are not limited thereto. That is, like the rod-shaped nanopatterns 65, a core region 65a may be surrounded by a shell region 65b and a portion of the core region 65a, that is, two end portions thereof may be exposed to the outside. While the nanopatterns 64 and 65 both having a core-shell structure are illustrated in FIG. 10, the exemplary embodiments are not limited thereto. Alternatively, some of the nanopatterns 64 and 65 formed on the two-dimensional material layer 12 may have a core-shell structure.

[0094] When the nanopatterns 64 and 65 have a core-shell structure, and the core regions 64a and 65a and the shell regions 64b and 65b are formed of different materials from each other, a degree of freedom of wavelength tuning of a multi-plasmon band may be increased compared to nanopatterns formed of an identical material.